21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

International Colloquium on
Lightning and Power Systems

Ljubljana 2017

Application and Performance of the Line Surge Arresters of the 110 kV Overhead Lines of the Croatian Transmission System

M. MESIĆ, S. PILIŠKIĆ, L. ĆURIN
Croatian Transmission System Operator Ltd. (HOPS), Zagreb
Croatia

I. UGLEŠIĆ, B. FRANC
Faculty of Electrical Engineering and Computing, Zagreb
Croatia

SUMMARY

This paper will present the overview of the LSAs implementation to the 110 kV overhead lines of the Croatian transmission network and performed analyses of the line surge arresters performances as well as the lightning statistics obtained from LLS database for the area surrounding the observed overhead lines.
The time and spatial the correlation of the relay protection system data with LLS data will be analysed in order to prove the impact of the lightning activities on the reliability of the overhead line as well as the contribution of the LSAs application to the improved overvoltage performance of the observed overhead lines.
Based on the given overview and performed analyses the conclusions will be made related to efficiency of the LSAs application for the protection of the lines against lightning and its further implementation within the 110 kV overhead transmission network of Croatia.

KEYWORDS

110 kV overhead line, outage, lightning performance, line surge arrester, lightning location system

Miroslav.Mesic@hops.hr

1. INTRODUCTION

Operation of the overhead transmission lines is largely influenced by the lightning activities. In particular, this is the case with the 110 kV overhead lines of the southern part of the Croatian transmission system where the transmission network is exposed to the intense atmospheric discharge activities so the number of their outages is significantly higher than for the rest of the Croatian transmission network.

Failure of the overhead line can be caused by the overvoltage induced in case of the direct lightning stroke to one of more of the phase conductors, lightning stroke to the tower or to the shielding wire followed by the flashover or due to the electromagnetic and electrostatic influences in case of the lightning stroke to the ground next to the tower or the overhead line [1].

Methods which significantly influence overvoltage performance of the overhead lines are: improving tower grounding resistance, increasing critical flashover voltage (CFO), line surge arresters application and shielding wire application [2].

In Croatian transmission network the standard protection of overhead transmission lines is a shield wire which intercepts lightning strokes so they cannot strike directly to phase conductors. In order to avoid backflashover, low tower grounding resistance is demanded. Due to the specific mountain environment of the southern part of the Croatia it is very hard to influence the tower grounding resistance. Therefore, surge arresters' installation has been applied for which the multiple studies have proved that it improves the lightning performance of the lines reducing the outage rate.

Croatian Transmission System Operator (HOPS) in 2007 started with the application of line surge arresters (LSA) to the transmission line 110 kV Ston - Komolac, which plays key role in electricity supply of wide area of town Dubrovnik and southern part of Croatian power system, as pilot project with the main aim to improve the overvoltage protection and lightning performance of this transmission line [3]. Following the positive experience and improvement of the reliability of the operation of 110 kV overhead line Ston - Komolac after to the LSAs application, in 2014 HOPS started with implementation LSAs in transmission network on the island Brač. In the period after the LSAs installation operational reports indicated significantly decreased number of outages of the observed overhead lines due to the lightning [4].

For the described cases the configuration of the LSAs installation on the line was obtained by the computer software simulation of the lightning performance of overhead lines [5,6].

After LSAs were installed to the overhead lines, the outages recorded by the relay protection system were monitored in order to obtain the conclusions on the performance of the overvoltage protection of the lines equipped with the LSAs. The correlation of the relay protection tripping data and lightning location system (LLS) data were performed and in general it proved the decreased impact of the lightning on the operation reliability of the overhead lines i.e. decreased number of the outages in correlation to the total number of the lightning activity detected by the LLS in the observed area.

LLS as part of LINET network has been established in Croatia at the end of 2008. The data on lightning activities for the time period from 2009 to now are available in LLS database which enables statistical analyses of the lightning activity and time-spatial correlation with operational events (faults, automatic reclosures, outages) registered by the relay protection system [7].

Taking into the consideration the experience gained during the ten year operation of the overhead lines equipped with LSAs, HOPS continues with the project of LSAs application to the 110 kV overhead lines of the southern part of the Croatian transmission network.

2. LSAs' OPERATION ON TRANSMISSION LINE 110 kV STON-KOMOLAC

Line surge arresters' installation to the overhead line 110 kV Ston – Komolac in 2007 in the scope of the pilot project represents the first experience of the application of line surge arresters in Croatian transmission network. The configuration of the surge arresters' installation on the overhead line was obtained by the computer software simulation using the overhead line parameters data and tower grounding resistance data as the input for the calculations. Experiences have proved that the simulation results are mostly influenced by the tower grounding resistance data quality. In addition, it was not possible to apply the simulation results completely due to of the relief structure surrounding terrain and difficult access to some of the towers.

First configuration of 110 LSAs was applied to the 110 kV overhead line Ston - Komolac in July 2007. Based on the permanent monitoring of the lightning performance and analysis of the effects of the arresters' configuration, the initial configuration has been modified twice during the first six years of the operation of the overhead line equipped with the line surge arresters. Also, during the 10 years of LSAs operation, 6 LSAs were dismantled due to the mechanical damages.

Final configuration consists of 104 LSAs as follows: 50 towers with 1 LSA installed in bottom phase, 24 towers with 2 LSAs installed, one in lower and one in middle phase, and 2 towers with 3 LSAs installed, one in each of the bottom, middle and upper phase.

The efficiency of the surge arresters was confirmed already after the first few years of the operation based on the monitoring of the outages data [3].

Table I shows the yearly numbers of the outages of 110 kV overhead line Ston – Komolac for the period before and after the LSA installation.

Table I Number of the outages of 110 kV overhead line Ston – Komolac (1995-2008)

Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**June 2007**	**July 2007**	**2008**
Day with the outage	15	13	5	17	18	13	9	18	11	10	11	13	3	3	8
Number of the outage	23	25	24	21	30	14	13	24	12	14	18	17	4	4	12

For the purpose of this paper the transmission lines failures (including automatic reclosures) registered by the relay protection system of the 110 kV overhead line Ston – Komolac were analysed and the time and spatial correlation with the LLS data was performed for the period from year 2009 to now when LLS data were available. Fig. 1 shows the yearly distribution of total number of outages and those caused by lightning on the observed OHL.

It is important to notice that in 2015 the substation Rudine for the connection of the wind power plant was connected to the 110 kV overhead line Ston – Komolac, but for the purpose of this paper the initial network topology was considered.

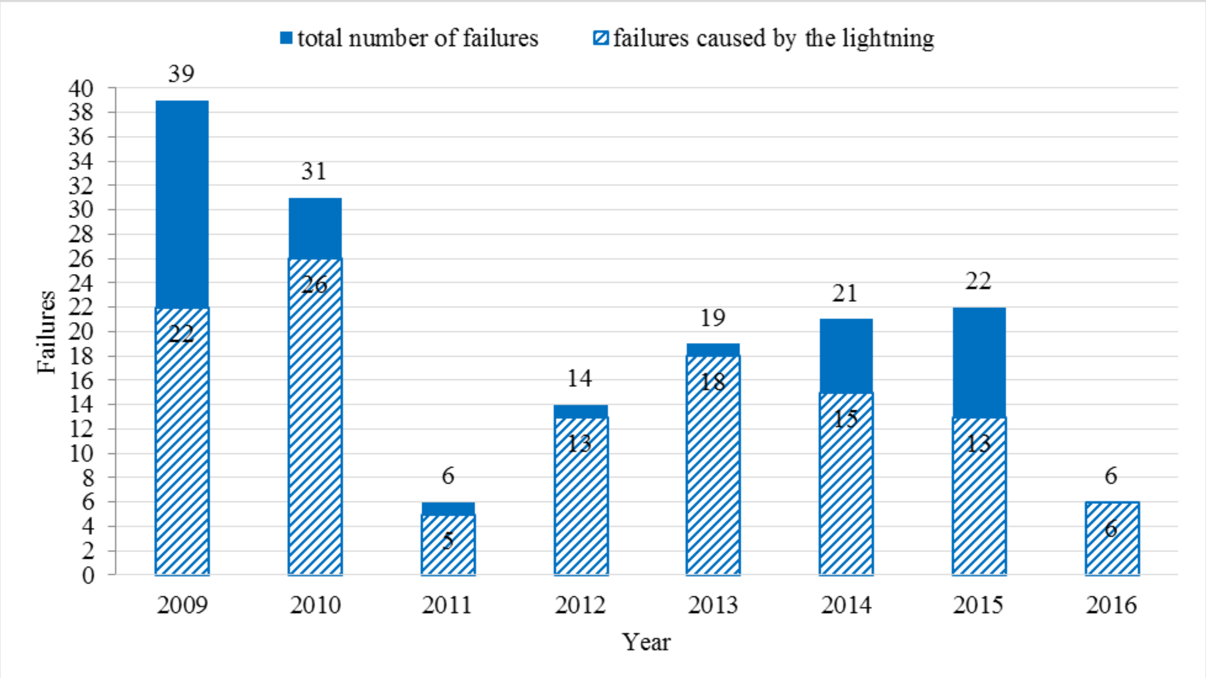

Fig. 1. Number of the failures of the 110 kV OHL Ston – Komolac (2009-2016)

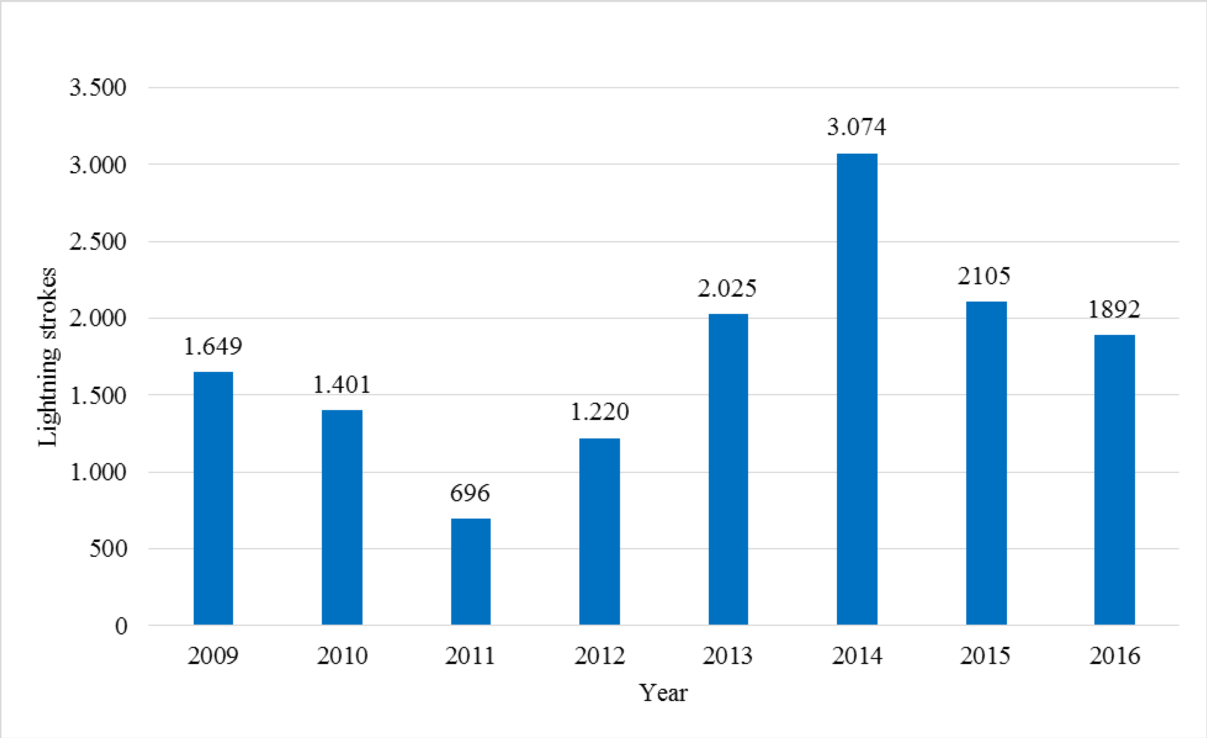

Fig. 2. Number of the lightning strokes within the OHL alarm zone (2009-2016)

Fig. 2 represents the lightning stroke distribution registered by the LLS within the alarm zones around the observed overhead lines for the period 2009-2016. From the figure it is possible to conclude that number of the 110 kV overhead line Ston –Komolac is in the correlation with the lighting activities within the observed area.

The LLS algorithm was improved in 2016 in order to be able to detect more lightning strokes of low current amplitude as well as more of the multiple strokes within the lightning flashes. Therefore, the number of the detected lightning strokes in 2016 is higher in comparison to the previous years although the lightning activities in general were below the average in 2016. The improvement of the LLS detection still needs to be quantified, but this explains the relatively low number of the overhead line outages in comparison to the number of registered lightning strokes within its alarm zone.

In addition, 49 of the LSAs installed to the 110 kV overhead line Ston –Komolac are equipped with the surge monitors (counters) which the number of discharges seen by the arrester as well as their current amplitude with time-stamp. Surge monitor device measures the discharge current amplitudes in 5 ranges: 10 – 99 A, 100 – 999 A, 1000 – 4999 A, 5000 – 9999 A and > 10000 A.

Although, during the operation of the LSAs some difficulties have occurred regarding the surge monitor readings and time synchronisation, certain conclusions can be done based on the surge monitor data analysis.

According to the distribution of the discharge current amplitudes as recorded by the surge monitors installed on the 110 kV overhead line Ston –Komolac and shown on the Fig 3., the highest number (70%) of all discharge currents are in amplitude range of 10-99 A.

Discharges with the current amplitude in ranges of 10-99 A and 100-999 A could be caused by the switching overvoltages or overvoltages induced by the cloud to cloud or cloud to ground discharges. Discharges with the current amplitude higher than 1000 A are most probably caused by the lighting activities.

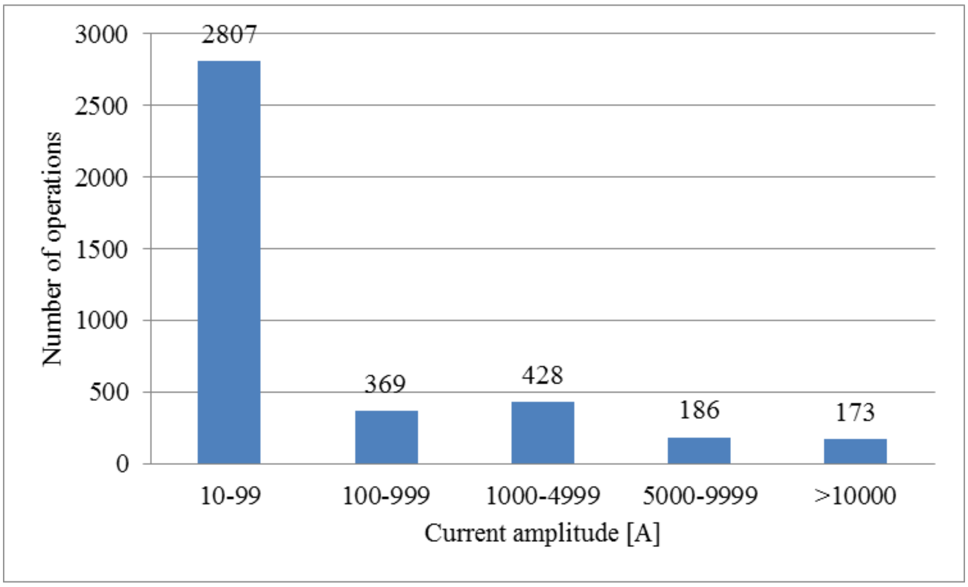

Fig. 3. Number of the LSAs’ discharge operation recorded by the surge monitors (2007-2017)

Fig. 4. shows the number of LSAs’ operation recorded by surge counters in bottom (C), middle (B) and upper (A) phase on towers on which there are more than one surge counter installed and for the discharge current amplitudes > 1000 A. It can be seen that there is significant number of operations recorded for the LSAs installed to the upper and middle phases. For the towers where there are LSAs installed in all three phases, the highest number of discharge operation has been recorded in upper phase and the lowest in the bottom phase.

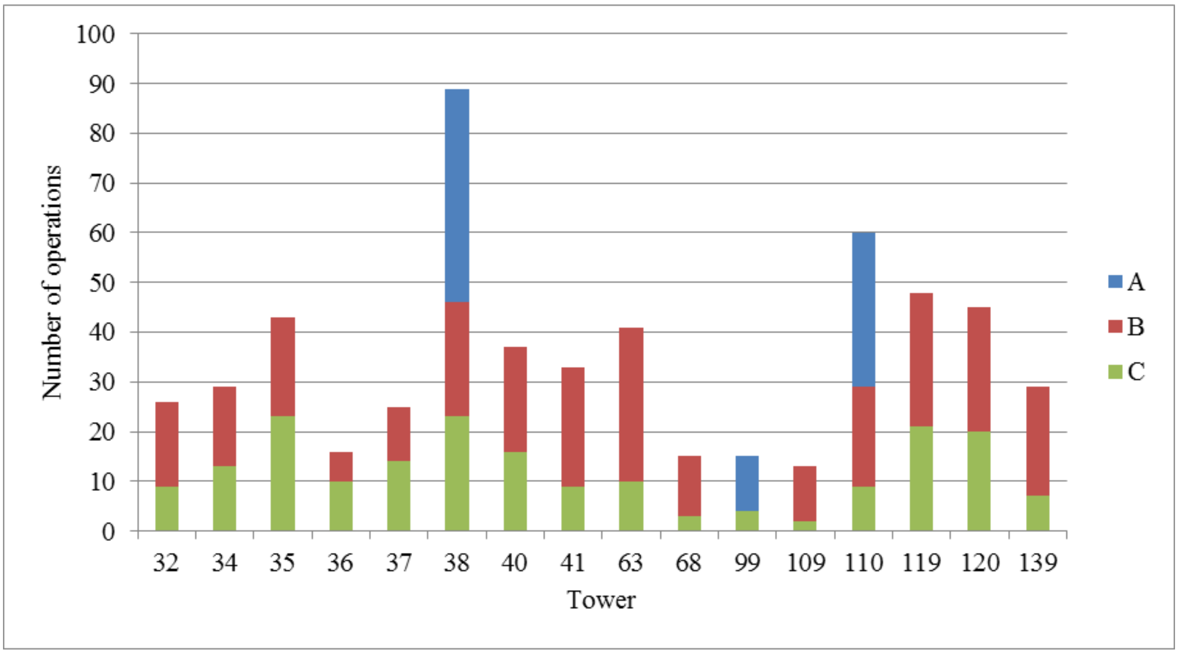

Fig. 4. Number of the LSAs’ discharge operation (2007-2017)

Further analyses show that the highest number of LSAs’ operation is recorded by surge counters on the overhead line section from tower 34 to tower 44. This overhead line section is in particular exposed to the lightning discharge activities. The overhead line section from tower 68 to tower 109 is not exposed to the significant lightning discharge influence.

As already mentioned grounding resistance of the towers influence the overvoltage performance of the overhead line significantly. Since the values of the measured tower grounding resistance can change during the overhead line operation, tower grounding resistance is measured periodically and on regular basis.

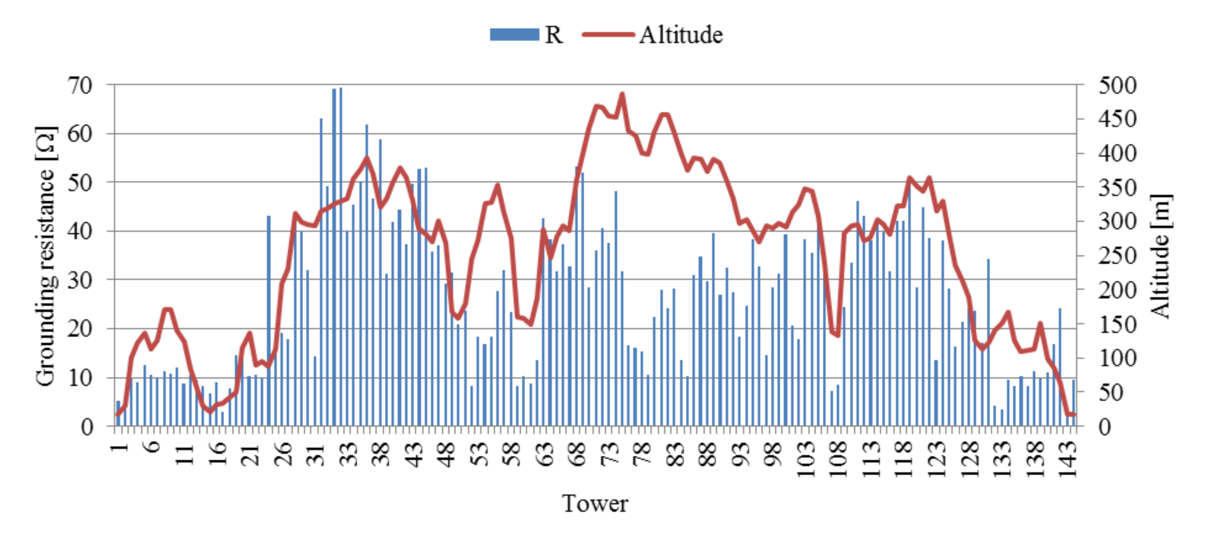

Fig. 5. Tower grounding resistance and altitude of the towers

Fig. 5. shows the tower grounding resistance measured in March 2017 in correlation with the location altitude for all the towers of the 110 kV overhead line Ston – Komolac. It can be seen that the tower grounding resistance values are higher for the towers located on higher altitude which is due to the configuration of the terrain on the higher altitudes, where the soil is mostly rocky and with high value of the specific soil resistance. Due to the high values of tower grounding resistance, the back flashovers occur frequently on the overhead line sections with the towers located on higher altitudes.

Moreover, there is a real time measurement system for the lightning transient currents monitoring installed on the two towers of the 110 kV overhead line Ston – Komolac [8]

Although the ten years long experience of the operation of the 110 kV overhead line Ston – Komolac equipped with the LSAs shows the improvement of the overvoltage protection performance of the line, analyses show that some improvements of the LSAs configuration are still possible. For the next phase of the analyses the new software simulation of the overvoltage performance of the 110 kV overhead line Ston – Komolac will be performed. As the new input data will be used the actual data obtain from all available different sources: relay protection system data on the overhead line operation and failures, LLS data on lightning activities in the area surrounding the overhead line, real time measurement system and last measured tower grounding resistance.

Based on results from the new software simulation the reconfiguration of LSAs installed on the line will be considered.

3. LSAs' OPERATION ON 110 kV TRANSMISSION LINES OF ISLAND BRAČ

In 2014 LSAs were installed to the 110 kV overhead lines of the island Brač in Croatia. Based on the data on the overhead line parameters and towers' grounding resistance the computer simulations of different line surge arresters' configuration were performed [6]. The final configuration of the surge arresters' installation obtained by the computer simulation was slightly modified due to the possibilities for favourable access to some towers. The final LSAs configuration of the OHL 1 comprises of 20 LSAs (15 towers with 1 LSA installed in bottom phase, 1 tower with 2 LSAs installed, one in lower and one in middle phase, and one tower with 3 LSAs installed, one in each of the bottom, middle and upper phase). The final LSAs configuration of the OHL 2 comprises of 25 LSAs (3 towers with 1 LSA installed in bottom phase, 8 towers with 2 LSAs installed, one in lower and one in middle phase, and 2 towers with 3 LSAs installed, one in each of the bottom, middle and upper phase).

Fig. 6 shows the yearly distribution of total number of failures and those caused by lightning on the observed OHLs.

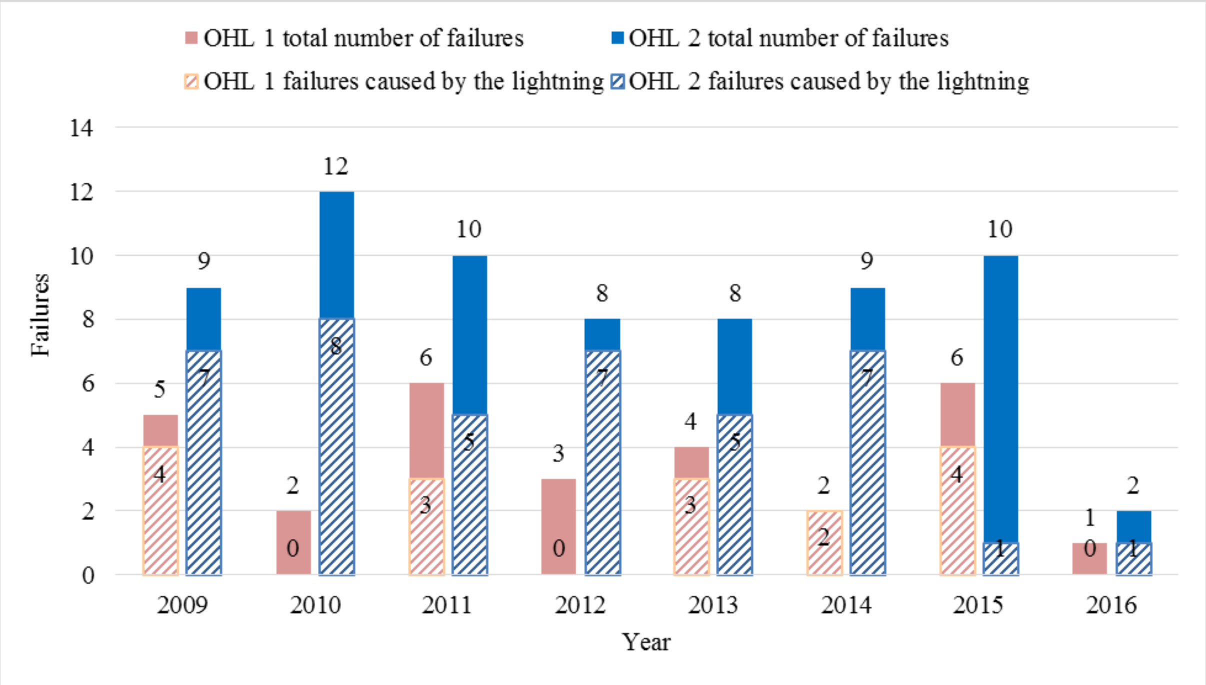

Fig. 6. Number of failures of the 110 kV OHL of the island Brač (2009-2016)

Fig. 7 represents the lightning strokes distribution registered by the LLS within the alarm zones around the observed overhead lines for the period 2009-2016.

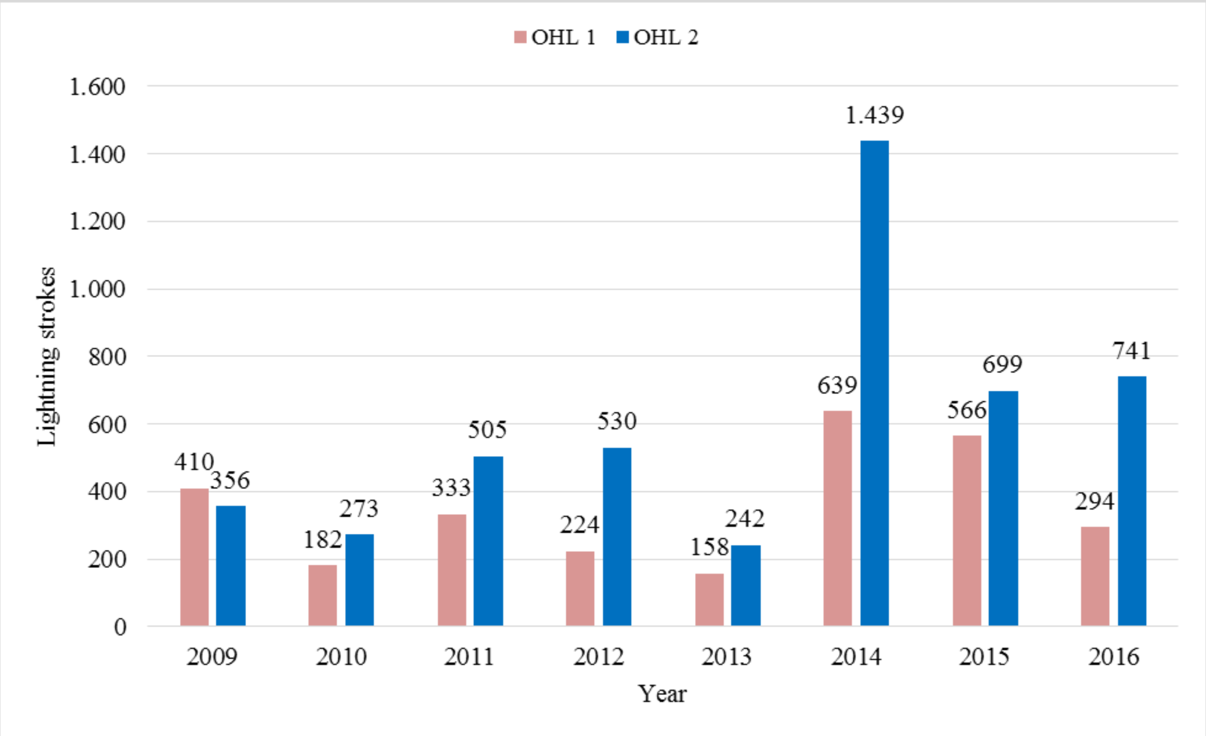

Fig. 7. Number of the lightning strokes within the OHLs alarm zones (2009-2016)

In [4] it has been shown that all of the failures caused by lightning in 2014 occurred after LSAs installation. The analysis of the lightning activities in the observed area showed that the 2014 was extremely lightning active and provided reasonable explanation for increased number of outages caused by lightning.

In 2015 there was increased number of the failures of the OHL 1 and decreased number of the failures of the OHL 2. In order to determine the cause of such failures distribution on the OHLs, analysis of lightning activities during 2015 and case by case correlations between LLS and relay protection data was performed and described in [4].

According to the distributions of the lightning strokes represented in the Figure 7 conclusions about the influence of lightning to the operation of the OHLs are possible. During the 2015 there were less lightning than in year 2014 in the observed area, but still above the yearly average (based on the eight year measured period).

In 2016 there were no failures of the OHL1 and only one failure of the OHL2 occurred. It has been already mentioned that due to the LLS algorithm improvement in 2016 the number of the detected lightning strokes in 2016 is higher in comparison to the previous years although the lightning activities in 2016 were below the average.

Finally, it can be concluded that after the LSAs installation the overvoltage protection performance of the 110 kV overhead lines of the island Brač related to the lightning activities in surrounding area improved significantly. Previous analyses showed that there are still some improvements of the LSAs configuration possible [4, 9], but it is still premature to bring the final decision on the LSAs reconfiguration.

4. PROJECTS FOR LSAs IMPLEMENTAION TO 110 kV TRANSMISSION NETWORK IN SOUTHERN PART OF CROATIA

The analyses of the operation of the Croatian transmission network show that the reliable operation of the one overhead line is influenced by the operation of the adjacent overhead lines. This is in particular case with the 110 kV transmission lines of the southern part of the Croatia which is significantly exposed to the lightning activities where the failure due to the same lightning stroke can occur simultaneously on two or more overhead lines. In such cases the reliability of transmission network operation could be endangered in the whole area. It is worth to notice that the reliable operation of the transmission network of the southern part of the Croatia is of utmost importance, not only for the security of electricity supply but also for the evacuation of the energy from the power plants, which installed capacity is increasing permanently.

The positive experiences with the LSAs implementations to the overhead lines showed that it improves the overvoltage protection performance of the overheard line and decrease the number of outages due to the lightning. Based on this experience and due to the need to ensure the reliable operation of the 110 kV transmission lines of the southern part of the Croatia, the options of LSAs installations on the remaining 110 kV transmission lines will be considered.

Overhead line 110 kV Ston-Ponikve located at the Pelješac peninsula was equipped with LSAs in 2015.

The design to the LSAs implementation for the rest of the overhead lines in the southern part of the Croatia, is finished and installation is expected by the end of the 2017 as follows: overhead line sections on the peninsula Pelješac and island Korčula of the 110 kV Ponikve –Blato, overhead line sections on the island Korčula and island Hvar of the overhead line 110 kV Blato – Stari Grad and overhead section on the island Hvar and island Brač of the 110 kV overhead line Nerežišća – Stari Grad.

5. CONCLUSION

Lightning protection performance of the LSAs applications on the 110 kV overhead lines of the Croatian transmission network was analysed.

Time and spatial correlation of the relay protection system data and LLS data was performed to determine the number of outages which occurred due to lightning. Lightning statistics were used in order to evaluate the efficiency of the LSA configuration in relation to the lightning activities in the observed area.

Although, the number of outages of the observed overhead lines in the relation to the recorded lightning activities decreased after the LSAs application was installed, some LSAs configuration improvements is still possible. For the final decision on the LSAs reconfiguration further analyses are needed. For the 110 kV overhead line Ston – Komolac there is a 10 years long experience of the LSAs operation as well as the data from different monitoring systems and last measured tower grounding resistance are available as the input for the further analyses and possible future LSAs reconfiguration. Further operational experience for the 110 kV overhead lines of the island Brač will be needed in order to obtain the data needed as the input for lightning protection performance analyses of the installed LSAs configuration and possible improvements.

Due to the positive experience gained from the first two projects HOPS will continue the application of the LSAs in order to improve the lighting protection performance of the 110 kV transmission overhead lines and in particular of those located in the Southern part of the Croatia where the lightning influence to the transmission network operation is significant.

ACKNOWLEDGMENT

This work has been supported in part by the Croatian Science Foundation under the project "Development of advanced high voltage systems by application of new information and communication technologies" (DAHVAT).
The authors gratefully acknowledge the Croatian Transmission System Operator Ltd. for organizational assistance and support.

BIBLIOGRAPHY

[1] Wurzer, G; Hübl, I.; Pack, S.: "A New Methodology for Electrical Tower Grounding in Practical Use", International Colloquium on Lightning and Power Systems, ICLPS 2016, Bologna, Italy, 2016.

[2] Thanasaksiri, T.: "Improving the lightning performance of overhead lines applying additionalunderbuild shield wire, " IEEE, 2013.

[3] M. Mesić, J. Radovanović, D. Škarica and S. Sadović, "The experience of operation of the overhead line 110 kV Ston-Komolac equipped with line surge arresters", CIGRE C4 Colloquium on Power Quality and Lightning, Sarajevo, Bosnia and Herzegovina, 2012

[4] M. Mesić, S. Piliškić, I. Uglešić, B. Filipović-Grčić and and B. Franc, "Performance of the Line Surge Arresters of the 110 kV Overhead Lines on the island Brač", ICLPS, Bologna, Italy, 2016

[5] M. Puharić, M. Lovrić, J. Radovanović, Ž. Ćosić and S. Sadović, "Line surge Arrester application Pilot Project", 27th International Conference on Lightning Protection, ICLP 2004, Avignon, France, 2004.

[6] M. Puharić, M. Mesić, S. Piliškić and M. Mijoč, "The Overvoltage Protection of the 110 kV Overhead Lines of the Island of Brač by the Line Surge Arresters' Application", ICLPS, Lyon, France, 2014

[7] B. Franc, M. Šturlan, I. Uglešić, A. Tokić and Z. Bajramović, "Development of customized tools for lightning locating data utilization", CIGRE C4 Colloquium on Power Quality and Lightning, Sarajevo, Bosnia and Herzegovina, 2012

[8] S. Sadović, T. Sadović, A. Xemard, M. Mesić, D. Marin, "Five Years of Experience of Ston - Komolac Transmission Line Lightning Measurement", ICLPS, Bologna, Italy, 2016

[9] M. Mesić, I. Uglešić, B. Filipović-Grčić, S. Piliškić, M. Mijoč and B. Franc, "Overvoltage Protection Performance of the 110 kV Overhead Lines after the Line Surge Arresters Implementation", IPST, Cavtat, Croatia, 2015